American Malleable Castings Association

The inside story of malleable iron issued...

Cleveland, Ohio

1915

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John A. Penton, Secretary.

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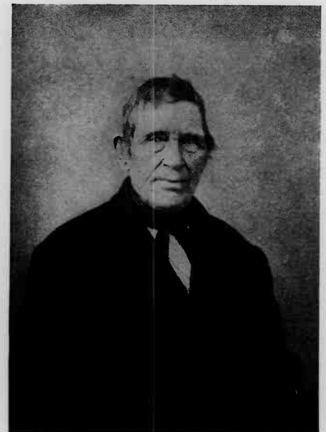

Seth Boyden

Discoverer of Malleable Iron in the United States

The

Inside Story of Malleable Iron

CHAPTER I

How Malleable Iron Was Discovered

AS compared with the early metallurgy of iron and steel, the birth of the malleable iron process is but as yesterday. Researches by eminent scholars, who have given the subject much careful investigation, indicate that the first iron used by prehistoric man journeyed to him through millions of miles of travel, as meteoric iron from the stars. It must be that such was the case, since how else than through the use of tools shaped from iron could such a stupendous work as the building of the pyramids have been accomplished, at a time when even the existence of iron ore was not suspected?

Think of them, built three thousand years before Christ, of the hardest and most enduring granite, which even today with modern tools is no mean task to shape. It is but fitting that these igneous rocks should have first been cut by meteoric iron.

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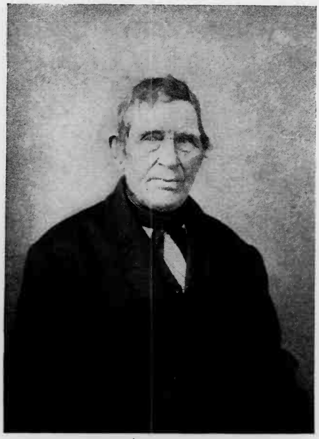

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spongy metal by heating it in the presence of charcoal, fanned by natural draft of the prevailing winds. The iron sponge was subsequently forged into a solid bloom by crude tools. The introduction of forced draft or blast from bellows, to accelerate combustion beyond the rate possible by means of natural draft was a natural evolution. Then came the development of bellows to such perfection that when operated by water power, the Catalan forge, as it was called, reached its highest efficiency.

Such was the state of the art among the Egyptians, the Chaldeans, the Assyrians, the Chinese, in India and elsewhere, back in the misty past many hundreds of years before Christ, and little if any change took place in the story of the winning of the metal until the end of the fifteenth century.

The Delhi Pillar

Erected 900 B. C. to commemorate the valiant deeds of Rajah Dhawa, there stands at Delhi's gateway, in India, a 20-ton column of forged iron blooms welded together, the over all length of which, including its beautifully designed and wrought capital, is nearly 50 feet. In the early middle ages, however, great skill had been attained in the working of iron and steel, and one has but to make mention of the Damascus blade to excite both wonderment and admiration for the genius of the early smiths.

From the beginnings of history to around the end of the fifteenth century, there had been a gradual change in the shape and size of the smelting furnace, accompanying the natural progress that had been made in mechanical equipment, and from the small open hearth of a few pounds capacity there was developed the shaft furnace that attained a height of 15 feet and a capacity of perhaps a ton a day. Up to this time cast iron, or in fact any iron that would melt and flow, was unknown, and the side of the shaft furnace had to be broken into each time the iron sponge was removed. A period now arrived when, owing to improved conditions of capacity and strong blast pressure, a much higher temperature than ever before attained in the furnace was reached.

The furnacemen, on breaking into the side

of the furnace to remove the iron sponge, noticed in the hollow recess of the hearth something never seen before: a little pool of molten cast iron, which on freezing conformed to every irregularity in the shape of its resting place. This was the birth of cast iron and the start in the evolution of the modern blast furnace.

It did not require much of an imagination on the part of those whose arduous duty it had been to break into the furnace to remove the spongy metal at frequent intervals to realize that if the entire charge in the furnace could be reduced to a fluid state, the hard and costly work of removing the metal in this manner would end, as it could by virtue of its fluidity be made to flow from the furnace through a hole located near the bottom of the hearth, and the further step was easily seen that it was now in their power to make a casting from this iron that would truly duplicate the form of any pattern they might make, to shape which had previously been the work of the smith at the cost of much time and labor.

Now, however, other difficulties were encountered due to the physical characteristics of the iron; the iron was white in color; too hard to cut with the tools they had, and as brittle as glass, for while the furnace temperature had now reached a point where the metal absorbed some 3½ per cent of carbon, thus making it less viscous when fluid and lowering the melting point of the metal some 600 degrees, this temperature was not sufficiently high to reduce from the ore enough silicon to render the iron both soft and strong.

Birth of the Malleable Process

As a matter of fact, it was not then known that a higher furnace temperature would through this means produce a softer and stronger iron, that would be gray in color instead of white. Steps were taken to see if these hard, brittle castings could not be made soft and ductile by some form of heat treatment, and thus was ushered in the beginning of the malleable iron process.

It was discovered that if these hard and brittle castings were surrounded by the very iron ore from which the pig iron was made,

placed in suitable fire clay or iron pots and heated to a little above redness for a number of days, the hardness and brittleness of the metal would disappear, and they would not only be tough and strong, but the fracture would be changed from white to black and velvety. The illustrious Frenchman, Reamur, was the first to write a treatise on this process, toward the beginning of the eighteenth century, while in this country it was the pioneer work of Seth Boyden that made possible the enormous industry for the manufacture of malleable iron castings that exists here today.

What the Malleable Process is

The rationale of the malleable iron process as now conducted in America may be understood from the following brief recital:

The reader must first be made acquainted with the difference between a pig iron whose fracture is gray and one that is white in fracture. The former is gray by virtue of the fact that when it was made in the blast furnace the temperature was high enough to allow a certain amount of an impurity in the ore called silica, the oxide of the metal silicon, to be reduced to that metal and alloy with the iron. Pig iron contains about 3½ per cent of carbon, and whether all of this carbon will unite chemically and alloy with the iron, thus forming a white iron that is hard and brittle; or whether this carbon will be prevented from alloying with the iron and separate from it in part or in whole, to be distributed throughout the metal in the form of graphitic flakes, depends almost wholly upon the amount of silicon in the pig iron.

It is clearly seen that a cast iron can be made that is gray in color and soft, or white and hard, simply by regulating the blast furnace temperature in such manner that either more or less silicon will be reduced from the ore and enter the pig iron. White irons are low silicon irons; gray irons contain enough silicon to force the carbon to separate from the iron in the manner described, in amount depending upon how high the silicon content may be.

To manufacture malleable iron castings, gray pig iron, low in those impurities injurious

to the finished product, is melted on the hearth of an air furnace and the operation continued until the silicon in the molten iron, through the oxidizing action of the furnace flame, is so far removed that the iron when cast is uniformly white in color. The castings are now very hard and brittle and would stand no service were they put to use in this condition, but, on the other hand, it is imperative that they be cast in this form, as otherwise the metal would not respond to the annealing treatment which they have to subsequently undergo, in order that they may be rendered tough, strong and ductile. This treatment consists in packing the white castings in iron pots, after each casting has been surrounded with a packing of iron oxide, and then placing these pots in suitably designed annealing ovens, where they must be maintained at a temperature of redness for some days.

Why White Pig Iron is Not Used

The reader might be curious to know why it is that since white iron castings are desired, the furnace charge is not made up of white pig iron instead of gray iron. Were this done, so much silicon would be removed from the iron during its stay in the air furnace that the castings would be too low in this element to anneal properly.

Each heat of iron that comes from the annealing furnace is tested thoroughly, first through the medium of tensile test bars, and then through test bars designed for dynamic drop tests, in which, if any brittleness exists, it immediately becomes manifest. All operations have to be conducted with great nicety; the furnaceman in charge of the air furnace must be a skilled operator in his line, while the annealer uses every possible precaution to see that the pots are kept at the correct temperature throughout the process, the ovens being equipped with delicate pyrometers that are constantly watched night and day to prevent injurious fluctuations in temperature. It is the fidelity with which all these operations are watched that determines whether the resultant product will be good or inferior.

CHAPTER II

What the American Malleable Castings Association Is

THE American Malleable Castings Association was formed for the purpose of aiding in every way possible a most important industry. One of its objects is to make a good product better, to offer to the master car builder, the automobile engineer, the manufacturer of agricultural implements and others, a dependable product, one easy to machine, uniform, free from blow holes and at all times reliable.

Following the policy of nearly all those engaged in the manufacture of ferrous products, the American Malleable Castings Association has secured the services of experts who, through training, practical experience and equipment, are competent to make a careful study of the processes of manufacture, who can periodically visit all the plants of the association and place the industry on a scientific basis. As a result, the product has been standardized. In the past, physical tests were not made uniformly and standards of practice varied at each plant; hence the difficulty of comparing the product of one plant with that of another. Today, all physical tests are made in identically the same manner at each plant of the association.

What has been the result of this co-operation, this close association of some 30 of the manufacturers of malleable iron, this desire for betterment in practice? *The effect has been to produce malleable iron castings that are always uniform, always dependable and of an extremely high standard of efficiency under the most severe working conditions.*

CHAPTER III

Thoroughness Developed by Research

EVERY individual as well as manufacturer has certain standards. As we all are human, necessarily these standards vary. Thoroughness as understood in one plant would be scoffed at in another. In other words, unless an association is formed with certain ideals in view, thoroughness, generally speaking, is capable of a wide interpretation. What have the manufacturers of malleable iron castings done in this direction? They have formed an association whose watchword is *thoroughness;* whose aim is to make possible the crystallization of an idea, almost prohibitive individually, to follow the example set by those industries which attained their great commercial success by thoroughness.

To accomplish this the American Malleable Castings Association established a physical and chemical laboratory in charge of a staff of noted metallurgists. In this way only could the metallurgical processes be investigated with thoroughness; in no other way could steps be taken toward further improving the process, toward the best method of testing the metal and the necessary investigation of all complaints regarding the product. Here, and here only, was it possible to discover whether the trouble was in the metal or in the faulty design of the pattern sent to the founder; and here only could a careful and thorough study of the best casting conditions be made.

CHAPTER IV

Co-Operation Begets Quality

A SPECIALIST is a man who starts in where everyone else leaves off. He is an intensive worker, an analyst, an acute thinker. In modern trade parlance, he is the court of last appeal. The mechanical engineer is a specialist, otherwise he could not design precision machines so accurate in their performance that 10,000 parallel lines can be cut on an inch length of glass. His training and skill make it possible for him to invent machines with movements so delicate and intricate that they improve on human handiwork.

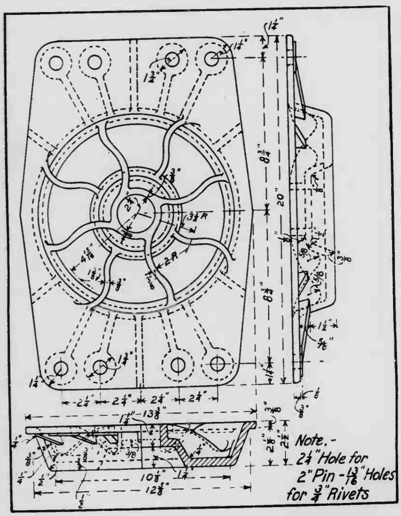

FIG. 1—PATTERN FOR MALLEABLE CASTING

The specialty of the malleable iron manufacturers is to know how to design a pattern so that castings made from it can be cast most perfectly; so that the metal will shrink the least. and offer the maximum strength for a given weight.

The malleable iron manufacturer knows his metal; he understands his conditions, and he is well informed as to how best to make any given pattern. However, while he may not know what function the part has to perform, he knows that the part can perform its function without failure, if it is made a little thicker here, a little thinner there, bracketed at one place and altered at another. His success as a malleable iron manufacturer depends upon this particular knowledge. In other words, he, also, is a specialist. Hence the mechanical or designing engineer, a specialist in his work, needs the services and knowledge of the malleable iron manufacturer; for both are specialists; each needs the other. This is simply another way of saying that co-operation means mutual interest.

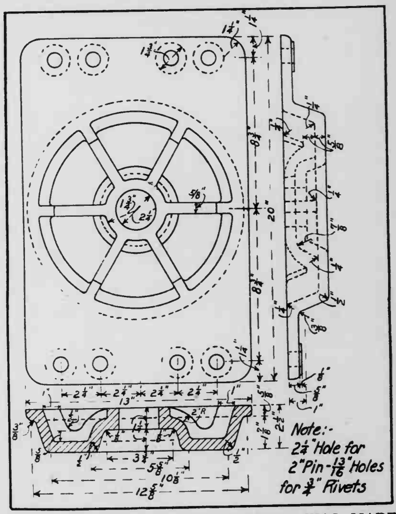

FIG. 2—PATTERN WHEN CASTING WAS MADE IN STEEL

Fig. 3

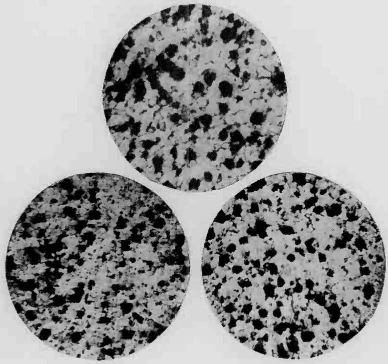

Fig. 4 Fig. 5

Fig. 3—Structure of Extreme Edge of 2-Inch Section

Fig. 4—Structure at a Point Between Edge and Center

Fig. 5—Structure Exactly at the Center

THESE MICROGRAPHS PROVE CONCLUSIVELY THAT THE STRUCTURE OF MALLEABLE IRON IN PIECES 2 INCHES THICK IS UNIFORM THROUGHOUT

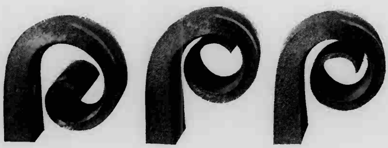

Fig. 6—Wedges Pounded into Scrolls by Blows of 70 Foot-Pounds on a Walker Wedge Testing Machine. These Wedges had Previously Been Machined to Remove the Skin, Thus Refuting the Statement That the Core of Malleable Cast Iron is Neither Strong nor Ductile

CHAPTER V

Fallacies Regarding Malleable

SOME men weave their own sophistry till their own reason is entangled. Fallacies are the result of superficial knowledge, an acceptance for facts what research and careful analysis will prove absolutely false. There are many fallacies, both in connection with the manufacture of malleable iron castings and with the physical characteristics of the metal itself. These wrong impressions, based mostly on hearsay, in time come to be handed down by word of mouth or through articles written for the technical press.

"All who told it added something new,
All who heard it made enlargements, too."

Some men will always talk knowingly about matters which they only know superficially; some men will never investigate the source from which they obtain their information; some men will write. Nobody can stop them.

It is ***not*** true that when the thickness of a section in a malleable iron casting exceeds ⅜-inch, it cannot be completely annealed throughout, while it ***is true*** that all parts of a malleable iron casting can be completely, thoroughly and uniformly annealed throughout every section, even if the sections are as thick as 2 inches. The microscope proves this fact and makes it incontrovertible.

It is not true that the strength and ductility of a malleable iron casting lies principally in the skin of the casting. If this were true, the metal in the skin of the casting would have to be as strong as a 0.60 per cent carbon

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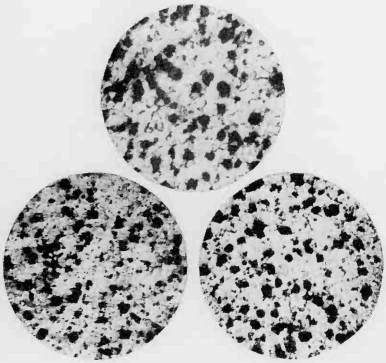

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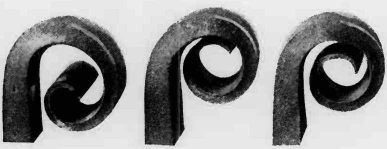

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FIG. 7—IN THE MALLEABLE EXPERT'S RESEARCH LABORATORY

steel, which will develop an ultimate strength of over 100,000 pounds per square inch. Otherwise the average strength of malleable cast iron would not be 40,000 pounds per square inch. Also, if the skin of malleable cast iron had the strength of a 0.60 per cent carbon steel, it certainly would not be ductile, for as the strength of steel is increased, its ductility diminishes. Yet we are told that the metal in the skin is not only stronger, but more ductile than that in the core.

"But facts are Chiels that winna ding, An' douna be disputed."

FIG. 8—WHERE CHEMICAL TESTS ARE MADE ON MALLEABLE IRON

CHAPTER VI

Facts for the Purchaser

WHEN molten metal, no matter whether it is iron or steel, is poured into a mold, the metal upon solidification crystallizes. The crystals will be very large; in fact, the higher the temperature at which the metal solidifies and the slower the cooling from that temperature, the larger will be these crystals and consequently, the more brittle and unreliable the casting. To remove the coarse crystallization and to replace it by a structure that will be exceedingly fine grained, is an easy matter, although it adds to the expense. If cast steel is heated to a temperature just above what is known as its critical point (the temperature at which it ceases to be magnetic) and is held at that temperature about 30 minutes, the coarse crystallization will be found to have disappeared and be replaced by crystals of extreme fineness. Through this treatment, unreliability gives way to superiority. Since most gray iron castings receive no heat treatment after being cast, their structure is in its most unreliable condition, while the crystals are the largest possible for the particular section in which they have been formed. Besides, every gray iron casting is in a state of internal strain that tends to weaken it.

Summarizing the foregoing, the purchaser

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Summarizing the foregoing, the purchaser

should bear the following facts in mind: In the manufacture of malleable iron castings, the white iron castings from the air furnace are packed in pots and heated for many days to a temperature just above the metal's magnetic point. This not only converts the hard and brittle castings into ones that are soft, ductile and tough, but makes the finest possible grain. After this, they are allowed to cool in the ovens very slowly until they are at a black heat. If a much higher temperature is reached, the castings will be badly scaled, while there will be a large loss to the manufacturer due to the oxidation of his pots.

The very details of the process itself are a guarantee both as to fineness of grain and freedom from internal strain. Therefore, without aim on the part of the manufacturer of malleable iron castings to bring about these desirable conditions, all malleable iron castings are free from internal strain and coarse structure, but unannealed castings of any kind may suffer from both of these troubles.

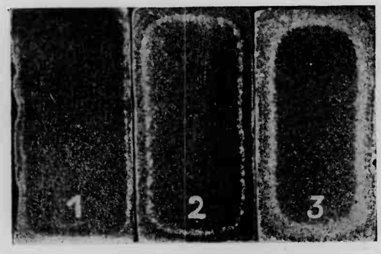

FIG. 9—STRUCTURE OF BARS ANNEALED ONE TO THREE TIMES

CHAPTER VII

Doubts Dispelled

NEVER be afraid of Doubt if only you have the disposition to believe. It is a well known fact that any iron or steel product can be burned by being heated at too high a temperature. As all malleable iron castings go through an anneal as one of the steps in the process of manufacture, these castings have been disparaged by some who are inspired by selfish motives. These detractors endeavor to place doubt in the mind of the possible purchaser by stating that malleable iron castings are frequently overannealed. Let us remove doubt. Five independent sets of white iron test bars were cast from as many ladles of iron. Each set consisted of eight bars. No. 1 of each set had one anneal; No. 2, two anneals; No. 3, three anneals, etc. The eighth bar of each set, annealed eight times, was held at a temperature

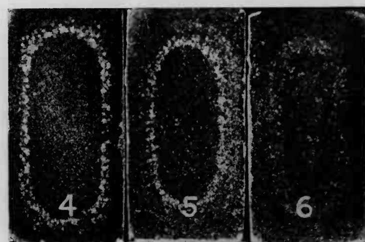

FIG. 10—STRUCTURE OF BARS ANNEALED FOUR TO SIX TIMES

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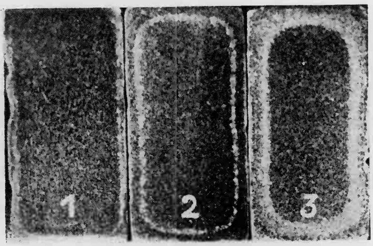

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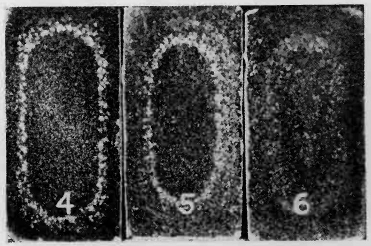

FIG. 10—STRUCTURE OF BARS ANNEALED FOUR TO SIX TIMES

of 1,500 degrees Fahr. for 480 hours, and at a lower temperature for a much longer period.

Now for the results. After the first thorough anneal, the toughness and ductility of the metal did not materially change; and not until the metal was annealed the fifth time was there the slightest deterioration in the strength of the test bars. The accompanying halftones were made from ordinary photographs of the polished and etched sections. The structural change that has taken place progressively in the metal can be easily seen. Bar No. 1, Fig. 9, has a narrow carbonless rim. In the second anneal a ring of pearlite is formed just under the surface, which would correspond to about a 0.30 per cent carbon steel.

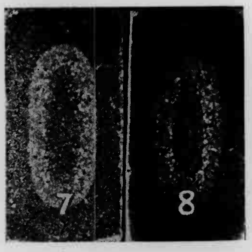

FIG. 11—STRUCTURE OF BARS ANNEALED SEVEN AND EIGHT TIMES

Note that on each successive anneal, Figs. 9, 10 and 11, this elliptical ring moves closer to the center of the section and increases in width. However, inside and outside of the ellipse, soft ferrite and free carbon, so typical of malleable cast iron of superior quality, is always found.

Burned malleable iron castings are a curiosity. To burn them the manufacturer must first ruin the costly pots in which the castings are annealed and in doing so consume a large amount of fuel uselessly. Will any manufacturer commit this act of folly?

"The end of Doubt is the beginning of repose."

CHAPTER VIII

Wide Field of Usefulness

ALL metallic structural products are restricted to certain limits of usefulness. The grade of steel used in the manufacture of telegraph wire, although its quality as measured by its freedom from impurities, may be the highest, would be wholly unsuitable if made into chisels. For structural material the carbon in steel must be fairly low; for tools it must be high; the former will machine with ease; the latter with difficulty. By virtue of its physical characteristics, each grade is suitable for a restricted field.

The best quality of wrought iron is lower in ultimate strength than the poorer grades, because the quality that is prized most in wrought iron is its ductility; and the higher this is the less its strength. Therefore, this product is out of its field when high ultimate strength is desired. Steel castings are very good for some purposes, but if perfect soundness and fine casting surfaces are required, they are out of their field.

When gray iron castings have an ultimate strength approaching 30,000 pounds per square inch, they are so hard that they machine with difficulty, and so brittle under shock that they are untrustworthy. Brass and bronze castings have many valuable qualities, but are costly, and cannot compete in the same field with the cheap ferrous products.

Malleable iron castings, by virtue of their unique physical characteristics, enjoy a very wide range of usefulness and encroach on the gray iron, steel and alloy field. With few

of 1,500 degrees Fahr. for 480 hours, and at a lower temperature for a much longer period.

Now for the results. After the first thorough anneal, the toughness and ductility of the metal did not materially change; and not until the metal was annealed the fifth time was there the slightest deterioration in the strength of the test bars. The accompanying halftones were made from ordinary photographs of the polished and etched sections. The structural change that has taken place progressively in the metal can be easily seen. Bar No. 1, Fig. 9, has a narrow carbonless rim. In the second anneal a ring of pearlite is formed just under the surface, which would correspond to about a 0.30 per cent carbon steel.

FIG. 11—STRUCTURE OF BARS ANNEALED SEVEN AND EIGHT TIMES

Note that on each successive anneal, Figs. 9, 10 and 11, this elliptical ring moves closer to the center of the section and increases in width. However, inside and outside of the ellipse, soft ferrite and free carbon, so typical of malleable cast iron of superior quality, is always found.

Burned malleable iron castings are a curiosity. To burn them the manufacturer must first ruin the costly pots in which the castings are annealed and in doing so consume a large amount of fuel uselessly. Will any manufacturer commit this act of folly?

"The end of Doubt is the beginning of repose."

CHAPTER VIII

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exceptions, and unless the pattern is over 6 feet long and the desire for great weight a factor, almost all castings under 400 pounds in weight can be cheaply made of malleable iron and will be much lighter for their strength than other castings; ease of machining is assured; brittleness is removed and soundness and reliability are guaranteed. The elastic limit of malleable iron is about 75 per cent of its ultimate strength, while the elastic limit of the soft steel casting is about 50 per cent of its ultimate strength. This means that the useful strength of the malleable iron casting is as great as that of the soft steel casting, and in addition, it is always sound; easier to machine and rusts more slowly; it will also stand more abuse under shock.

Brass and bronze castings will machine easier than those of malleable iron, and can be made sound, but they are much more costly, will not stand the abuse under shock that the latter are capable of enduring, and by degrees the malleable casting is taking their place.

CHAPTER IX

Real Economy

REDUCTION of cost can be resolved into two factors: Cost of production and cost of materials. There seems to be no immediate limit to the lowering of the former, for little by little the machine tool builder is making

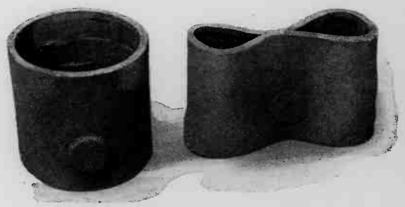

FIG. 12—MALLEABLE PIPE CANNOT BE BROKEN

one machine tool do, in a more accurate manner, what previously was not as well accomplished by two or three.

By virtue of the new alloy steels, these machine tools can take deeper cuts at speeds three times as great as when carbon steel was used for the purpose. Nor is the end yet in sight, for newer alloy steels give greater promise still, and so the production engineer, through improved organization, proper layout of plant, the use of alloy steels for tools and the latest machinery, bids fair to eclipse

anything he has yet been able to accomplish.

To take full and complete advantage of these possibilities, however, the machining properties of the raw material must be considered. The same machine tool at work on several different metals might have to operate at 50 feet per minute on one, whereas it could be speeded up to 100 feet per minute on another and to 250 feet per minute on a third.

One of the most prized characteristics of malleable cast iron is the speed at which it can be machined; also its freedom from hard spots and inequalities, the absence of blow holes and the fine surface after machining should be considered. The substitution of the malleable iron casting for the steel casting or steel forging means economy all along the line; a heavier cut at greater speed, no discards after machining due to the discovery of blow holes, less cost per pound of metal and great reliability.

The improvement in the manufacture of malleable castings has kept pace with the improvement in the machine tool. Malleable cast iron can well be called *economy metal*, for it enables the machine tool to work at its greatest speed and it is less costly per pound than steel.

CHAPTER X

Service the True Test

WHAT part of the automobile chassis has to stand the greatest abuse in service? If this question were put to the automobile engineer, the answer would undoubtedly be, the hub. Those who have toured must realize the severe and sudden shocks that are transmitted to the hub by the wheel, on getting into or out of a deep rut in the road, on hitting stones or other obstructions, on crossings, etc. Yet the concern which manufactures the greatest number of automobiles per year uses a malleable iron hub; the next two in output are similarly equipped, and so likewise are many of the less frequently seen cars. *This much is certain*: If the malleable iron hub had not given service of the highest kind, its use would be discontinued.

As a rule, the malleable iron casting is used where others have failed; where there is liability of failure under shock; where service is indispensable, and where dependability must be assured.

On the standard railway car, the draft gear is probably that part which receives the greatest abuse in service. The most popular types are made of malleable iron; the Miner, the Westinghouse, the Farlow and the Cardwell, and of these there are thousands in use and thousands in process of manufacture.

The testing machine, chemical analysis, the microscope, are all useful in indicating what may be expected of any given structural material. It is, however, easier to indicate than achieve.

The true test is the one shown through service. That is achievement.

CHAPTER XI

Malleable Specifications

By Enrique Touceda

(Reprinted from The Iron Trade Review)

NO ONE should attempt to draft a set of specifications for any material, unless by virtue of his familiarity with both its physical properties, and process of manufacture, he is in a position to avoid making meaningless provisions, ones that may prove incompatible with any of the others; or that might operate to prevent the manufacturer who understands his business from reaping the full benefit of his skill.

In formulating specifications for malleable iron castings, the engineer, unfortunately, has been handicapped to a great extent through a lack of opportunity to become well acquainted with the details of the process; first through the policy of secretiveness practiced by the manufacturer in the past, but which happily has now entirely disappeared; coupled with his inability to find on this subject a trustworthy literature for self-instruction, so easily obtainable in the case of the metallurgy of any of the other ferrous products.

Owing to this, most engineers in the preparation of specifications for malleable iron castings, have resorted to about the only thing left for them to do under the circumstances, that is, ascertain what others had done in this connection, and either copy bodily the specification that appeared best, or modify, or add to its provisions such matter as judgment indicated would better adapt it to their particular needs.

That this is true may be readily ascertained by anyone who will take the trouble to look over the numerous specifications that have issued during the past few years. It will be acknowledged readily that the majority of them have been practically derived from one model, that they are children of the same parent, whose chief defects they have very faithfully inherited.

As I view it, those who have attempted to draft a set of specifications covering this material, have at the very beginning of their work made one fatal mistake, in that they have thought it necessary to pattern after and ape the character of specification that has been made for steel, failing to realize the many reasons why such a course must lead to confusion, and to the introduction of matter that on its face stamps the writer as incompetent in this particular field.

In order to make clear what is meant by this statement, let us see what steps the engineer takes in the formulating of specifications for carbon steel.

He first protects himself as to *quality,* and with the knowledge that the quality of steel is measured by the lowness of the phosphorus and sulphur content, he places an upper limit on these two elements that must not be exceeded. Having safeguarded himself as to quality, he next makes provision to obtain a steel that will be suitable for the purpose for which the steel is to be used; stiff, if that is the property desired; ductile, if that be the physical characteristic sought. He is able to provide for either of these conditions, or intermediate ones, by setting a definite limit as to

the carbon content on one hand, or the ultimate strength on the other, either provision attaining the same end, for it is well known that strength, hardness and stiffness increase as the carbon content is raised, within the limits at least of structural material. In short, the lowness of the phosphorus and sulphur is the measure of the quality only, while the appropriateness or suitability of the steel for any given purpose is determined by the carbon content.

As a further safeguard, and in order to protect himself against the acceptance of steel which while conforming to the chemical requirements, may have been injured at some step in the process of manufacture, and which consequently will be defective structurally, provision is made whereby the steel must stand the amount of elongation and reduction of area that should normally accompany some particular carbon percentage or some particular ultimate strength if that be substituted in its place.

FIG. 13—MALLEABLE IRON KNUCKLE BEFORE TESTING

Now from the standpoint of composition, what is it that determines *quality*, in the case of malleable iron? Is it established by the lowness of the phosphorus and sulphur content? Does the carbon content establish the suitability of the casting for any particular purpose? Should limits be placed on the silicon and manganese content as frequently is done in the case of steel? Let us discuss these things and see if we can arrive at any definite conclusions.

In the case of phosphorus, we know that combined carbon exaggerates its evil effects, which is therefore least felt in those products that are very low in combined carbon, such as wrought iron, or malleable iron, where in most cases it is entirely absent.

If the reader will refer to the specifications adopted by the American Society for Testing Materials, covering lap welded iron boiler tubes, staybolt iron and refined wrought iron, he will find no mention made of the permissible amount of phosphorus and sulphur content allowable in any of these products. As a matter of fact, composition is not considered at all, and nothing is specified but the physical requirements.

FIG. 14—MALLEABLE IRON KNUCKLE AFTER TESTING

If a malleable casting contains less combined carbon that does wrought iron, why should restrictions be placed on the phosphorus content in the former case, and not in the latter, especially, in view of the fact that there is no product concerning which the engineer desires a stronger guarantee as to quality than staybolt iron? He surely must have good and sufficient reasons for permitting its quality to be measured solely by pro-

visions which govern its physical properties.

In connection with the manufacture of malleable iron, there is absolutely no temptation on the part of the maker to purchase pig iron higher in phosphorus than is perfectly safe, for he can obtain at no extra cost whatever an unlimited supply in which the phosphorus will not exceed 0.16 per cent.

Actually, while the specifications of the American Society for Testing Materials permit an amount as high as 0.200 per cent, and the Society of Automobile Engineers 0.225 per cent, I can vouch that in the case of more than 30 of the manufacturers, the phosphorus content of their product is within 0.18 per cent.

Cases exist where a manufacturer is so located, that due to freight rates, he is able to purchase charcoal iron at a less cost than coke iron, and while the former has a phosphorus content considerably higher than the majority of malleable coke irons on the market today, it must not be forgotten that it is only a comparatively short time since no coke iron was used in a malleable mixture, and that the best castings made in those days were as good as the best today.

As to the effect on quality of sulphur and manganese, which it is convenient to consider together, experience has shown that in order to obtain tough and ductile castings, it is necessary to maintain a certain ratio between these two elements. For instance, malleable iron castings with a manganese content of 0.36 per cent, and a sulphur of 0.03 per cent, all other elements being present in correct proportion, would result in an inferior product, though both of these elements are present in an amount that is not prohibited by any specification that I have ever seen. As a matter of fact, the low sulphur would be taken as an indication that the product was superior. The amount of sulphur that should accompany this manganese content, is 0.12 per cent, an amount that would condemn the castings in the eyes of many, and cause them to be rejected irrespective of what the physical tests might show.

The manufacturer should be permitted to adjust these elements to accommodate the

composition of the pig iron he has in stock. There is no temptation for the manufacturer to purchase high sulphur iron. Such iron is made in the blast furnace through accident. not by design, and the amount made is very scarce comparatively. The difference in price between the high and low sulphur iron is about $0.75 per ton, and I will leave it to the reader to figure out how long it would be before the price would be raised for this grade of iron if the demand for it was great. When such iron is purchased, it is for one of two reasons: to use some on the annealing pot mixture, or to adjust the sulphur content so as to obtain the proper ratio of manganese and sulphur. It is much easier to obtain low sulphur iron than it is low manganese iron.

It now remains to be seen if it is wise to specify the permissible amount of silicon and carbon in the castings, which as in the case of manganese and sulphur are interdependent, and should be considered together. In order to make this clear to the engineer, a few words in connection with the process of manufacture are necessary.

Ordinary gray iron, iron in which most of the carbon is in the graphitic state, cannot be made stronger and tougher by thermal treatment, because the graphite that is present will remain after the treatment, as it originally existed in the iron, and any change effected in the combined carbon will simply make the iron softer and weaker.

It was discovered many years ago, however, that if no graphite is present in the cast iron, so that the entire amount of the carbon content is chemically combined with the iron to form the very hardest constituent that can occur in any ferrous product, such iron through proper heat treatment could be made very strong and tough. The malleable iron process is founded upon this discovery, and consists in first making white iron castings, free from graphite, from gray pig iron in which most of the carbon is graphitic, and then heat-treating the former so as to break up the hard carbide of iron into soft iron and free carbon.

In order to obtain white iron castings from gray iron pig, all that is necessary is to melt the pig iron in the presence of an oxidizing atmosphere, which serves to remove enough silicon to enable the remaining carbon to chemically unite with the iron which it does in certain definite proportions. Having obtained the white iron castings, the next step is to heat-treat them, in order to break up the hard carbide of the white iron, into soft iron and free carbon, when the castings will be very tough and ductile, provided the sulphur-manganese and silicon-carbon ratios in the white iron were so adjusted that they offered no obstructions to reactions that take place during the heat treating.

Very superior results can be obtained when the silicon-carbon ratio is 1.25-2.30 per cent, and also when this ratio is 0.50-2.80 per cent, and there are intermediate ratios that yield good results.

From this it can be seen that if the engineer is going to specify anything as to silicon, he should at the same time consider the carbon content, and vice versa. When, however, he comes to consider the proper carbon for a specified silicon, it must be further stated that the ratios I have quoted above refer to the silicon-carbon in the white iron, specifications for which are not made. During the heat-treatment, some carbon is removed from the white iron, and the amount removed depends upon the thickness of the section, so that the matter is complicated by having to take this fact into consideration.

The above facts are briefly presented for the purpose of demonstrating how meaningless it is to make specifications similar to most of those that have been made in the past.

It is known to all who have studied this matter, that the structure of malleable iron conforms more closely to that of wrought iron than to steel, and it is generally lower in combined carbon than the former.

If engineers are willing to pass upon the quality of their wrought iron through physical requirements only, why should they object to doing the same in the case of the malleable iron castings?

If the engineer will make a specification for these castings, in which a limit is placed on the lowest strength and ductility that will be tolerated in tension; design a good test bar for such a test; do the same for transverse test and center load; then make provisions to cover allowable variations in weight, dimensions, appearance of surface, absence of cracks, etc., he will be able to protect himself through the medium of a simple, direct and sensible specification.

The introduction of meaningless or unnecessary provisions simply results in trouble all around, and in confusion on the part of the inspector and the management. As an example of meaningless provisions, let us quote one from perhaps the most popular specification now in use:

FIG. 15—SMASHING BLOWS HAVE LITTLE EFFECT ON MALLEABLE CASTINGS

"Malleable castings shall neither be 'over', nor 'under' annealed. They must have received their full heat in the oven at least 60 hours after reaching that temperature." Now, not only is no information given as to what temperature corresponds to "full heat", but if 60 hours is specified as being allowable to hold the castings at that temperature, is it right to hold the manufacturer accountable if the castings are "under annealed" provided

they have been held at "full heat" for that length of time? If they are under annealed, the physical tests will disclose that fact very quickly and it is unnecessary to dictate to the manufacturer how he shall conduct his anneal, but if this instruction is deemed essential, it should at least be imparted by one who understands the process. The proper temperature to use to anneal white iron castings is about 50 degrees Fahr. above the critical temperature, and the critical temperature varies somewhat with the composition of the white iron.

The metallurgy of malleable iron is very complex, and as the lowness of phosphorus and sulphur do not determine the quality of malleable iron, and as the percentage of carbon does not determine the particular use to which the casting should be put, it is well to follow what has been done in connection with specifications for wrought iron, rather than for steel.

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